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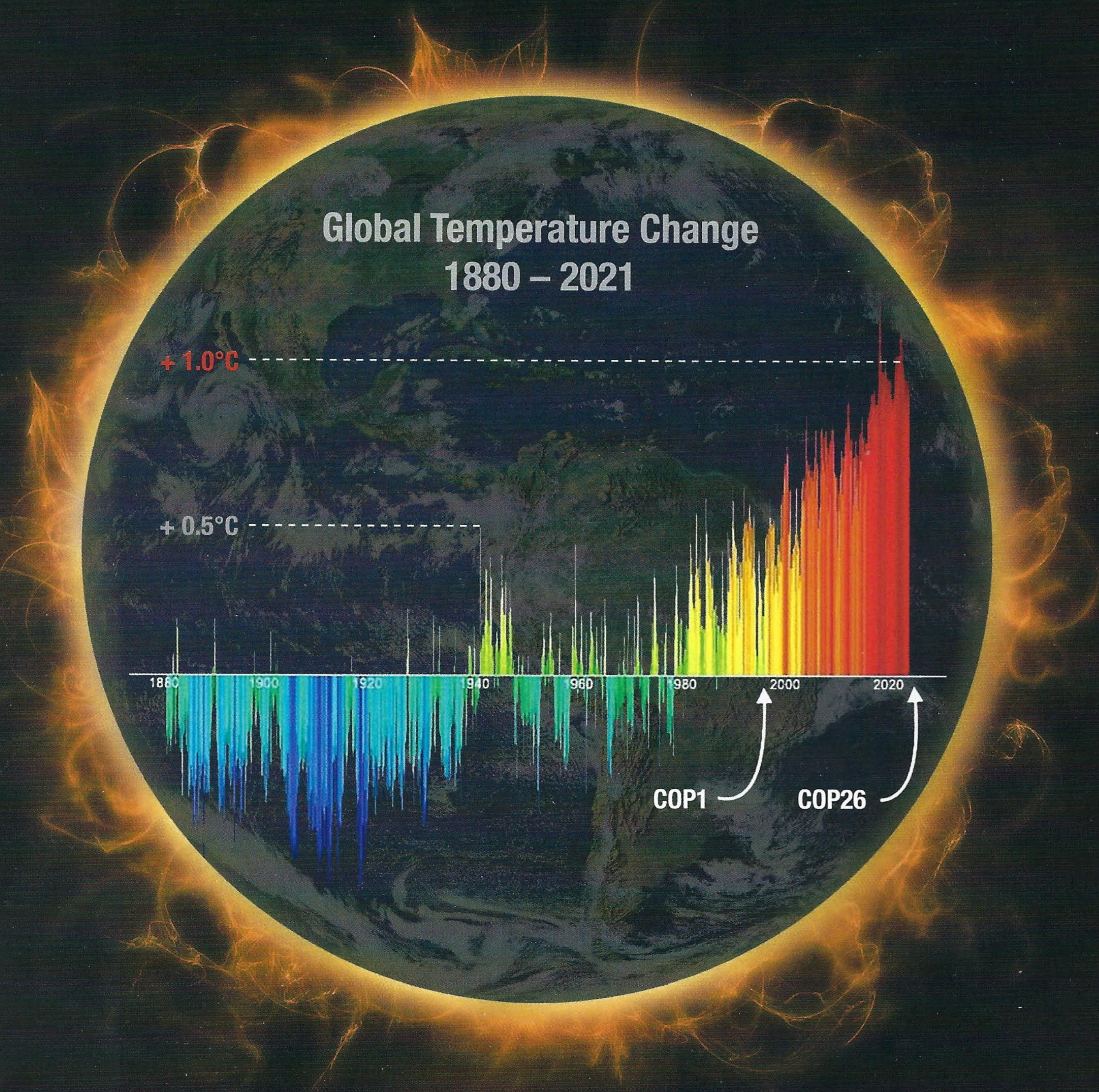


Goal is to limit the rise to 1.5°C by 2100

Net Zero by 2050? Hope is not a Plan

by Peter Baldwin, President base-e

Despite a frenzy of international climate summits, conferences, legislation, promises, pledges, commitments and recommitments, I see little chance for meaningful action before it's too late to reverse climate change.

The closing days of 2021 will be remembered as a major climate change inflexion point defined by the almost simultaneous convergence of six major events:

☐ **COP26 Glasgow Summit**. 2021 UN climate change conference.

☐ **UN Emissions Gap Report**. 2021 Assessment and update

☐ **HR 3684 Congressional Act**. The "Infrastructure and Jobs Act of 2021"

☐ **HR 5376 Congressional Bill**. The "Build Back Better Act" (pending 2022 action).

☐ **U.S. DOE Energy Program Review**. Status of 2021 flagship energy projects.

☐ **US Pathway to Net-Zero**. Long-term 2021 strategy for meeting 2030 and 2050 goals.

Event One - COP26

At the recent annual United Nations ***Conference of the Parties*** **("COP")** conference held in Glasgow, a "Global Climate Pact" was adopted by nearly 200 countries declaring the 2020s as the ***decade of climate action and support***.

My observation: Coal-to-Gas fuel switching will remain the primary climate change initiative in developed countries. Also, unabated natural gas plants will be the primary source of grid power supporting the worldwide electrification of economies and transition to 100% renewable energy by 2035.

• The Washington Post has described unabated coal power plants as "those that do not capture their carbon dioxide emissions using a ***nascent technology***, not currently available on a commercial scale." This is Best Available Control Technology (BACT) language in action which limits any potential applications of Carbon Capture and Sequestration (CCS) for gas turbines at the power plant level as "unproven".

• Carbon capture and sequestration will remain "unproven" and not be deployed at any future power plants -- coal, gas or otherwise. I am unaware of any new plants having CCS, nor of plans for retrofitting existing plants, rendering its consideration irrelevant.

The COP26 pact calls on countries to accelerate "the phasedown of unabated coal power and of inefficient subsidies for fossil fuels." A last-minute objection by India changed the original "***phaseout***" to "***phasedown***"**,** further weakening the fossil fuel initiative, and who knows what "inefficient subsidies for fossil fuels" means?

• My take is that phasing down of "inefficient subsidies for fossil fuels" would permit the use of unabated natural gas-fired gas turbine power plants and become the accepted standard in Europe, the same as it is in the U.S.

• India and China must use CCS to deal with their growing energy needs and their dependence on lignite, with its potentially negative impact on amine-based, post-combustion carbon capture systems.

• China is still building 43 new coal-fired power plants in 2021, with approximately 200 more planned. However, China will no longer provide financing for coal-fired power plants outside of the country.

• Russia plans to remain a huge hydrocarbon exporter and stands to benefit from the opening of the Arctic territories.

French President Macron announced that France will "relaunch the construction of nuclear reactors" for the first time in decades.

The U.S., Russia, and France now describe nuclear, the once-ne-glected technology, as a key part of their decarbonization plans. China is planning 150 new reactors in the next 15 years. Bloomberg News observes that's more reactors than the entire world has built since 1986.

• Meanwhile, the nuclear phase-out in Germany is on course to be completed by 2022, following more than a 60% cut in capacity over the past decade. Plan is to replace this shuttered capacity with renewables and unabated gas.

- And, the European "green taxonomy," a lengthy regulation that specifies which forms of energy investment qualify as "green", is expected to list nuclear as climate-friendly. They will also list unabated natural gas with CHP and/or district heating as "green enough" to qualify for financing.

At COP26, the Hydrogen Council CEO offered that hydrogen could contribute over 20% of global carbon abatement by 2050.

- Hydrogen surfaced initially in Europe as an alternative to fossil fuels, but now of growing interest worldwide.
- Use of H_2 as a fuel does not appear to present insurmountable technical issues. But serious obstacles associated with the piping and distribution systems are not yet resolved. Also, significant economic and safety issues not illuminated.
- There are several concepts, but no real standards have emerged. However, hydrogen hubs such the ones in Rotterdam, Teesside and Hamburg have been announced.
- Expected reliance on production and use of "blue" hydrogen during the transition to "green" will require a commitment to CCS technology to limit CO_2 emissions from its production.

Observation: It is increasingly obvious that the world will not be meeting absolute CO_2 reductions targets, and "***CO_2 Emissions Intensity***" is now being served up as the key metric.

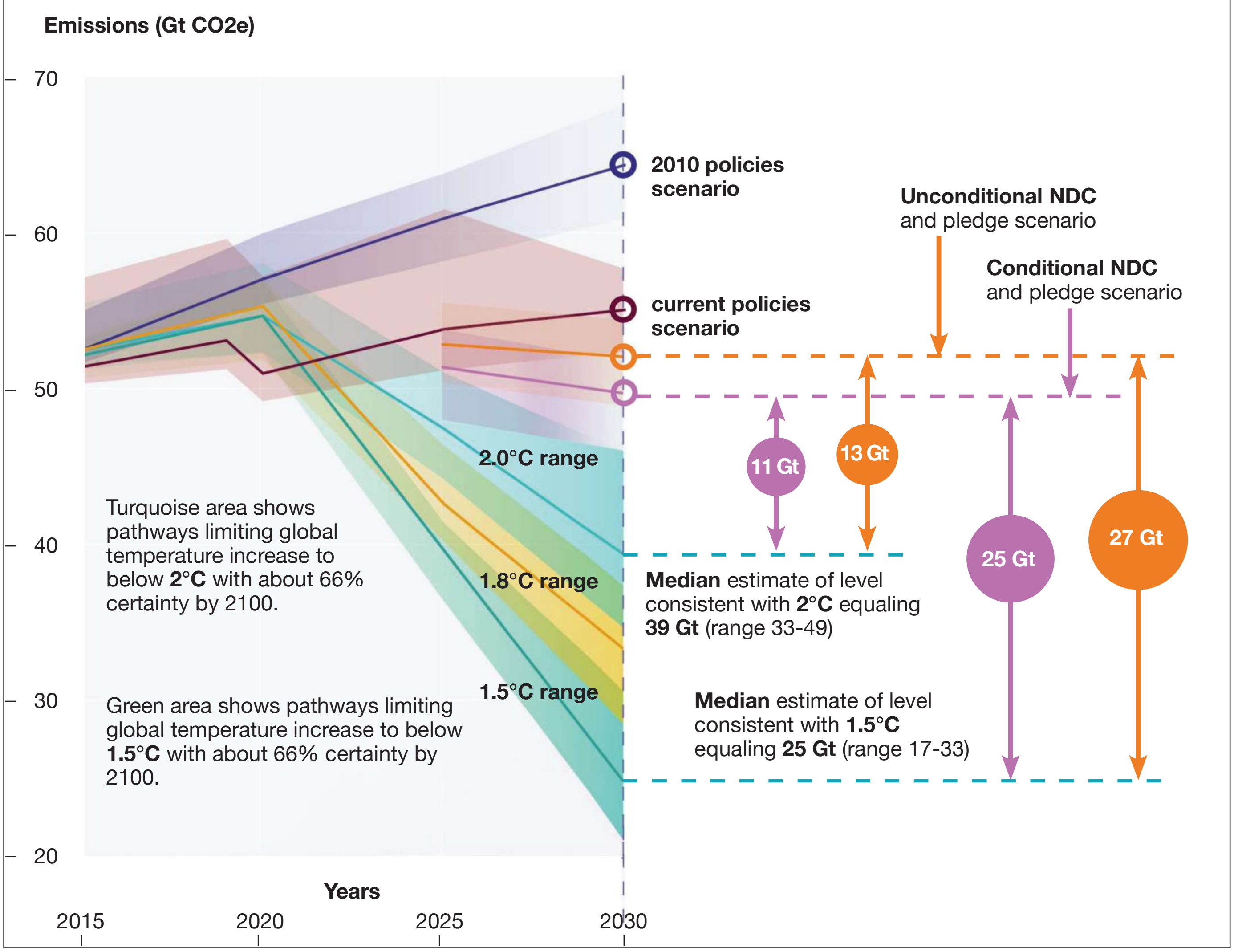
The only good news here is that China and India seem to have the same mindset so perhaps agreement on performance against this metric is feasible.

Of note, neither Russia, China nor Brazil had a meaningful presence in Glasgow.

Event Two – The Gap Report

The United Nations issued its annual Emissions Gap Report for 2021, under the title ***"The Heat Is On - A world of***

Fig.1. Global annual greenhouse gas emissions (2015-2030) and emissions gaps for various scenarios. By 2030, the gap under unconditional NDC and pledge scenario, and the target level needed to meet 2°C temperature-rise limit, will be 13GtCO2e; the gap for 1.5°C goal will be 27GtCO2e. (Source: UN Emissions Gap report 2021)



climate promises not yet delivered" with an Addendum released in November to update the emissions gap for 2030.

The emissions "gap" is the difference between predicted carbon emissions at a point in time and those emissions said to be required to meet the target global temperature rise limits by the end of the century.

Another term found in the discussion, **'*carbon budget*'**, refers to the amount of CO_2 that the atmosphere can still absorb compatible with limiting global temperature rise to the Paris target of 2°C (or to the 1.5°C stretch goal) by 2100.

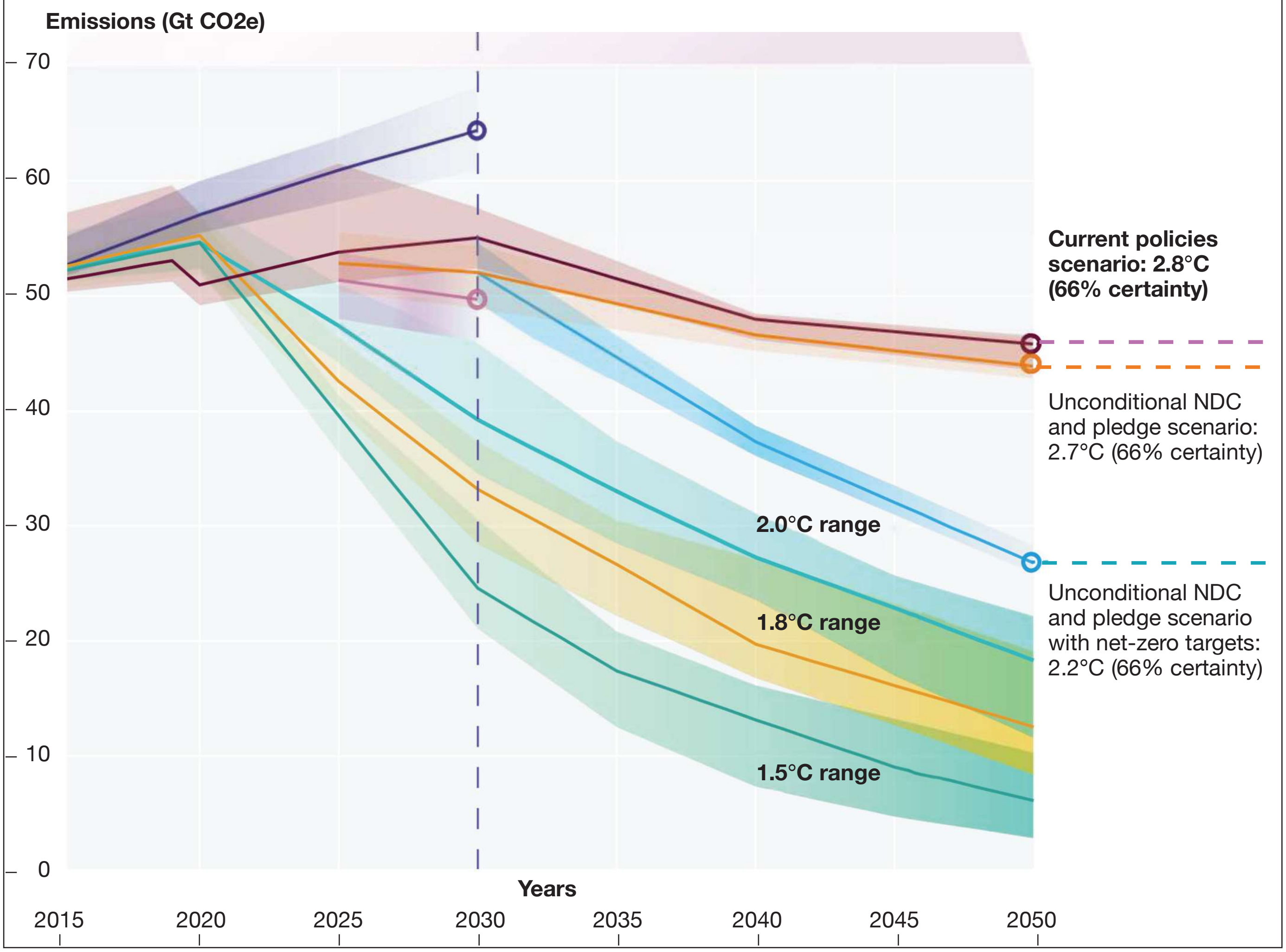
The world will burn through its remaining carbon budget (for 1.5°C rise limit) in 11 years without big emissions cuts, scientists say. Some say there is even much less time.

To put this in perspective, at the time of the 2015 Paris Agreements, the CO_2 budget for the target 2°C rise limit was set at around 1,000Gt, or about 30 years-worth of emissions at the then current rate of 35Gt CO_2. (Gt = Gigatonnes = billion tonnes.)

- Most recent estimate is that remaining budget for CO_2 is ~460Gt (for 1.5°C rise limit).
- In just six years, humanity has burned through more than half of its remaining carbon allotment, says Sarah Kaplan (Washington Post).
- Annual emission rates continue to increase, despite global agreement to take action. After a short dip in 2020, global emissions are almost back to pre-pandemic levels.
- Preliminary estimates for 2021 indicate that global CO_2 emissions will reach 33Gt.
- When all other greenhouse gases (GHG) are considered, total annual emissions for 2021 will be about 51Gt-CO_2e (CO_2 equivalent), as indicated on the Emissions Gap Chart, Figure 1.

Looking ahead to 2030, under the so-called "current policies" scenario, the UN report indicates that total annual GHG emissions would **grow** to 55GtCO_2e.

Fig. 2. Global annual greenhouse gas emissions (2015-2050) and emissions gaps under various scenarios. Latest climate promises for 2030 under unconditional NDCs and pledge scenario put the world on track for a temperature rise this century of at least 2.7°C. New commitments for "Net Zero by 2050" improve this temperature-rise forecast to 2.2°C. Policy makers talk about the need for "negative emission technologies" to meet limits under the 2015 Paris Agreements. (Source: *UN Emissions Gap report 2021*)



Although about 10GtCO_2e below the level projected under the earlier "2010 policies scenario", this is still well above the target 2030 emission levels, namely **39Gt**CO_2**e** and **25Gt**CO_2**e**, consistent with staying within the 2°C and 1.5°C temperature-rise limits, respectively.

The estimated annual emissions in 2030 based on various pledge/promise scenarios show little improvement. Under a scenario based on the **unconditional** nationally determined contributions (NDCs) and pledges, emissions are reduced to about 52GtCO_2e, and to ~50GtCO_2e under the **conditional** NDCs and pledge scenario**.**

Based on these estimates, the "gap analysis" indicates that annual emissions in 2030 must be **13Gt**CO_2**e** lower than the announced **unconditional** NDC pledges to stay within the 2°C temperature-rise limit -- and **27Gt-**CO_2**e** lower for the 1.5°C goal.

If the **conditional** NDCs are considēred, these gaps are reduced by around 2GtCO_2e (to 11GtCO_2e), and 3GtCO_2e (to 25GtCO_2e) for the 2°C and 1.5°C limits, respectively.

Update: The most recent Emissions Gap Report Addendum (released November 2021) finds new and updated NDCs take **only 7.5% off** predicted 2030 emissions**, while 30% and** ***55%*** **reductions are needed** to meet the 2.0**°C** and 1.5°C Paris goals, respectively.

- Latest international climate promises ***for 2030*** put the world on track for a temperature rise this century of ***at least 2.7°C.*** (See Figure 2, extending emissions projections to 2050).
- With inclusion of new commitments of **net-zero by 2050**, expected temperature rise is reduced to ***2.2°C***.
- Policy makers now talk openly about "negative emission technologies" (e.g., direct air capture and CO_2 removal) coming into play later in the century to meet Paris Agreement goals.

Event Three - U.S. HR 3684

As the COP26 summit conference ended, the U.S. almost simultaneously launched its US$550 billion **Infrastructure Investment and Jobs Act,** HR 3684, signed into law on November 15, 2021 which, regarding climate change, should be viewed as a "Supply-side" initiative.

- It declares carbon capture and storage (CCS) technologies both 'safe and necessary' for reducing hard-to-abate emissions from the industrial sector (i.e., industrial CCS).
- Affirms that CCS technologies, ***including Direct Air Capture (DAC),*** must be deployed at large-scale in coming decades to remove carbon dioxide directly from the atmosphere.
- Although not stated specifically, CCS deployed at power plants is still rendered "unproven" by the BACT threshold, effectively establishing unabated-gas as the de-facto standard!
- This reflects holdover from Clean Power Plan (2015) and EPA view of unabated gas as the "bridge fuel" and "clean enough".

HR 3684 acknowledges that carbon capture and storage will require a backbone network of shared carbon dioxide transport and storage infrastructure.

- **Storing** CO_2 **and Lowering Emissions (SCALE) Act** *was included as part o*f the infrastructure package to drive deployment of CCS technologies.
- The Act supports interconnected CO_2 transport systems that collect CO_2 from capture sources and deliver it to shared storage sites.
- Objective is widespread CCS investment at scale needed to achieve economy-wide emissions reductions.

Legislation would suggest that the U.S. is going "all-in" on hydrogen, direct air capture. small modular (nuclear) reactors, and solid oxide fuel cells/ electrolyzer cells (SOFC/SOEC), as key elements of its long-term climate change strategy.

Hydrogen deployment. HR 3684 sets aside $8.0 billion to support development of at least ***four regional clean hydrogen hubs*** to demonstrate production process, delivery, storage and end use.

- Defines **clean** hydrogen to mean that 1 kg of hydrogen cannot yield over 2 kg of CO_2-equivalent greenhouse gas emissions during production.
- Effectively requires 80% carbon capture from steam methane reforming (SMR) processing of natural gas, which produces approximately 10 kg CO_2 per kg H_2 (on average).
- Methane emissions would count in "CO_2 equivalent" metrics. Goal is a national clean hydrogen network to facilitate a clean hydrogen economy.
- $1.0 billion is included for programs to reduce the cost of hydrogen produced using electrolyzers to less than $2 per kg by 2026.

Direct air capture. The bill sets aside $3.5 billion to create ***four regional direct air capture hubs*** for deployment of projects to capture and sequester (or utilize) at least 1,000,000 metric tonnes (i.e. ***0.001Gt)*** of CO_2 emissions from the atmosphere per year. (Note: For reference, the United States emits ~6.0Gt annually.)

Nuclear and hydro. HR 3684 authorizes $6.0 billion to advance the development of Micro and Small Modular Reactors.

- **Micro-Reactor** refers to an advanced nuclear reactor with a power rating of 50MW or less.
- **Small Modular Reactor** refers to an advanced nuclear reactor rated at 300MW or less, which can be constructed and operated combined with similar reactors at a single site.

Also under the Infrastructure Bill, the U.S. will subsidize continued operation of its carbon-free nuclear and hydro fleets.

- Includes $6 billion Nuclear Credit Program to help **keep U.S. reactors operating**.
- Creates a real-world cash incentive to offset the competitive advantage now enjoyed by unabated natural gas plants.
- For hydro, the Bill allots $553 million to maintain hydro and pumped storage capacities.

Fuel cells. An expanded program to support fuel cell development appears to be based on a **Distributed Energy/CHP** strategy that would utilize existing natural gas distribution system to fuel SOFC/SOEC gas turbine fuel cells.

- Reversible units can produce electricity running forward or hydrogen running in reverse (operate as electrolyzers).
- Minimizes need for an extensive hydrogen distribution network.
- Remains to be seen how large these units can be economically viable.
- To date, hybrid SOFC/GT designs are limited to less than 4:1 gas turbine pressure ratio.

CO_2 collection and distribution, The Infrastructure Bill recognizes need to construct CO_2 collection hub and distribution systems to cope with emissions from DAC and blue hydrogen activities. To be funded under the $6.0 billion SCALE Act.

Mining property. There is $500 million earmarked to support clean energy demonstration programs on current and former mining properties. A gamut of eligible technologies includes:

- solar, micro-grid; geothermal, and direct air capture
- fossil-fueled power generation with carbon capture and sequestration
- energy storage, including pumped hydro and compressed air
- advanced nuclear generation

Observations: Direct air capture representations rarely include CO_2 compression and its associated investment and energy costs.

- Not clear whether these costs are shifted into the hub and distribution costs.
- Energy storage will remain an essential component of renewables integration and grid reliability.
- To date, the transportation fuels issue is absent from these discussions, despite the transportation sector accounting for about 35% of total U.S. energy consumption and 30% of greenhouse gas emissions.
- The application of CCS technology for gas-fired power plants is ignored, absent from consideration, which I believe is intentional.
- Fossil-fueled electricity generation with carbon capture and sequestration is in HR 3684, but more as political "cover" than an "intent to deploy".
- CCS for power generation is not supported since it would open door to continued coal use. This position enables, even encourages, continued use of unabated gas as "bridge fuel".

Event Four – Build Back Better

The $2.2 trillion U.S. social spending plan known as the "Build Back Better" framework (HR 5376), just shelved as of this writing, contains **$555 billion for climate change and clean energy investments –** one quarter of the total funding under consideration.

HR 5376 should be viewed as a "Demand-side" initiative, a catch-all for anything relevant to the cleanup of electric power production and reduction of CO_2 emissions.

Proposed $555 billion investment, if passed, would represent the **largest single investment** in the U.S. clean energy economy in history. The objective is to set the U.S. on course to meet its 2030 climate targets, achieving a **50% reduction in power sector greenhouse gas emissions,** below 2005 levels.

The 2015 Clean Power Plan had promised 32% reduction of 2005 levels (~2.4 Gt). HR 5376 claims to cut "climate pollution" immediately and deliver over a billion metric tonnes (>1.0Gt) in greenhouse gas emissions reductions by 2030.

Clean energy tax credits. To be expanded by a new 10-year production tax credit Section 45X to incentivize production of **qualified** clean hydrogen.

Defined as hydrogen produced by a process that achieves at least 40% reduction in greenhouse gas emissions compared to steam-methane reforming. Production would have to start in 2028.

Existing Section 45Q incentives would be modified or expanded for a range of ***carbon capture facilities*** including:

1) direct air capture facilities greater than 1,000 metric tonnes (0.000001 Gt) capacity,
2) electricity generating facilities greater than 18,750 metric tonnes (0.00001875 Gt),
3) other facilities greater than 12,500 metric tonnes (0.00001250 Gt).

Tax incentives increased for purchase of electric vehicles (to $12,500) and for installing solar panels on private homes.

Clean electricity performance program (CEPP). Electric utilities would have an initial target reflecting their 2019-2020 average share of "clean" electricity:

- Defined as electric power generation with carbon intensity of 0.1 metric tonnes CO_2 equivalent per megawatt-hour (tCO_2e/MWh) or less.
- Includes most renewables and nuclear energy, but excludes coal and natural gas generation without carbon capture.
- Utilities exceeding their initial target receive bonus grants of $150 per MWh greater than 1.5% above the prior year's clean electricity sales.
- Utilities that do not achieve their annual target would be penalized $40 for every MWh shortfall, thereby putting a price on CO_2.
- It is unclear if this is to be applied on a facility-wide or individual unit basis.

Observations: Widespread implementation of carbon capture and sequestration or simply "***abatement***", frequently mentioned in HR 5376 could be the key to transition from our fossil fuel economy to one built around renewables.

Effectively, its deployment could provide an immediate impact **at scale** without supply chain disruptions associated with rapid closure or stranding of existing assets.

Parties on both sides have "staked-out" their customary positions, talking past one another and leaving no room for discussion and compromise on the middle ground.

Senator Manchin (D-WV), who holds the deciding vote, has no interest in carbon capture and sequestration which he views as compromising the ability of coal and natural gas to compete. Nor does the Sierra Club, which sees CCS as allowing continued use of fossil fuels, including both coal and natural gas.

Adding carbon capture to gas-fired power plants remains the middle ground, allowing for a planned transition to a clean energy economy without destroying the value of existing assets. But this discussion is far from over.…..stay tuned!

Event Five - DOE Reviews

Coincidently, the US Dept. of Energy in November 2021 conducted its annual review of flagship energy programs:

1) Local Energy Action Program (LEAP) projects.
2) University Turbine Systems Research (UTRS) program, and
3) Solid Oxide Fuel Cell (SOFC) technologies

Solid oxide fuel cell with gas turbine (SOFC/GT hybrids) that can attain 70%-plus net electric efficiency in various cycle configurations look good for many applications. Execution from the start should aim for simplicity, not be too complicated.

Using **reversible** SOFCs to generate electricity and solid oxide **electrolyzer cells** (SOECs) to produce hydrogen seems complicated when all the reversibility and heat recovery variations are introduced.

But the combination may allow hydrogen to be produced where used, avoiding many of the hydrogen pipeline and distribution issues.

They seem most suitable for distributed generation, but challenging to implement at utility grid scale. Open question for me is how big we can build them to achieve scale.

Carbon capture and sequestration is evident in most of the transition and end-state plans going forward. This includes the support of direct air capture and now, more broadly, carbon dioxide removal (CDR).

A major driving force behind support of CCS deployment, at scale, is its application for commercial production of ***clean "blue" hydrogen*** via steam-methane reforming (SMR) of natural gas needed in bulk for transition to a hydrogen economy.

It must be acknowledged that the effluent from the SMR process (8 to 12 kg of CO_2 per kg of H_2 produced) has a carbon content literally comparable to that of "dirty coal" which poses an environmental issue that must be addressed.

The EPA is now talking about **95% carbon capture** as the standard, effectively shifting cost from their new favorite, **direct air capture**, back onto the power plant or capture system operators.

When proponents of DAC technology call for its adoption, they never define its components or energy consumption – and only mention CO_2 compression in passing. My personal problem here is that DAC is being served up as "essential" whereas capturing CO_2 at a power plant source is still being dismissed as "unproven".

Carbon dioxide removal, aka "negative emissions" or "carbon drawdown" aims to address the primary human source of climate change by removing carbon dioxide from the atmosphere to be permanently stored underground or under the ocean floor.

Removal methods being considered include afforestation, agricultural practices that sequester carbon in soils, bio-energy with carbon capture and storage, ocean fertilization, enhanced weathering, and direct air capture combined with storage.

Consider this: the CO_2 concentration in a gas-fired power plant flue gas is about 4% (vol) which is ***100 times greater*** than the 400 ppm level in the atmosphere.

By ***not*** applying carbon capture directly to the power plant exhaust, it would take 1,000 standard sized DAC units (each rated at 0.001 Gt capture per year) to offset the emissions from one unabated 400 MW gas-fired combined cycle plant. ***How and why does this make sense???***

Hydrogen distribution. Michael Shelton, CEO of the ACTS Company, aired concerns regarding hydrogen piping and distribution systems during LEAP program review sessions.

He cited several serious technical issues which suggest that the design and construction of high-content hydrogen distribution pipeline systems will be challenging:

- 20% (vol) is the practical limit for mixing H_2 into existing carbon steel natural gas pipelines
- Greater than 20% H_2 requires 316SS grade stainless steel pipe material
- H_2 pipeline diameters must be doubled to match the energy content of natural gas
- Some sections of H_2 pipeline may require double-wall construction
- There are the obvious concerns over leaks and safety
- Compression cost and energy consumption will be significant

Bottom line: Existing natural gas pipeline system cannot be repurposed to serve as an H_2 distribution system. I don't see such distribution systems as either practical or achievable. There may be dedicated local systems associated with power plants, and/or return-to-base vehicle fueling applications similar to existing compressed natural gas systems.

A more practical approach would be to use the existing natural gas distribution system to support the SOFC/SOEC-GT systems that could produce H_2 at its point of use, minimizing the H_2 system cost and complexity.

Further observation: Discussions and HR 3684/5376 legislation are dedicated to selling a ***hydrogen future*** coupled with carbon capture and sequestration.

• Although the advocates are selling a "green" hydrogen future, language and funding embedded in the recent US legislation suggest we are preparing to use "blue" hydrogen to support the expected quantities in demand.

• Future clean "blue" hydrogen production processes under development based on auto thermal reforming (ATR) and partial oxidation (POX) are too complicated to have any climate change impact within the time available.

• GTW wrote about gasification (i.e. partial oxidation) plus a shift-reactor, to produce hydrogen fuel for combined cycle as a "capture ready" IGCC concept 15 years ago –since abandoned as too complex.

Event Six – Long-term Strategy

The just-released (November, 2021), U.S. ***"Pathway to Net-Zero GHG Emissions by 2050"*** identifies calendar targets and "sort of specific" actions to realize the pathway.

To meet the ultimate goal of Net-Zero in 2050, the intermediate targets relative to a peak level of about 6.6 Gt-CO_2e in 2005, are reductions of better than 25% and 50% in 2025 and 2030, respectively (see Figure. 3).

Committing to "Net-Zero" by 2050 is an IOU which relies on "Net Negative Contributions" where CO_2 emitters purchase emissions credit IOUs, with the expectation that the sellers of these credits will perform as contracted. (It is not clear to me what a default looks like.)

The Pathway Report also identifies the "2050 Generation Mix" assumptions behind the forecast net zero CO_2 emissions and makeup and basic elements of the predicted mix, i.e. fossil-fired generation (with and without CCS), nuclear and renewables (Figure. 4).

Total generation is seen to increase substantially through 2050 due to expected expansion in electrification, with increased use of clean electricity in new applications in transportation, industry and buildings.

Renewable generation increases rapidly to keep pace with demand, and share continues to expand as fossil share declines. Note the introduction of fossil with CCS into the mix in the early 2020s as fossil without CCS declines.

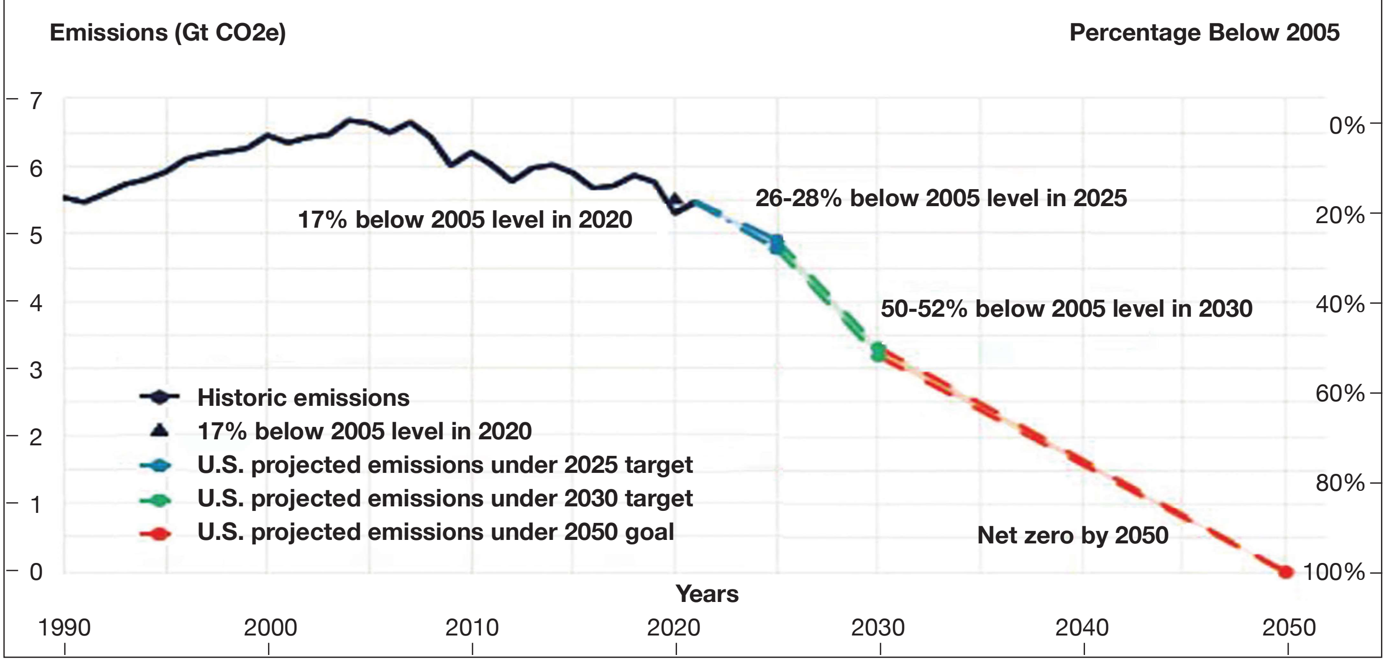
Note also that the U.S. emissions forecast relies on ***~1.0 Gt negative contributions*** from "land sinks" and Carbon Dioxide Removal (CDR) measures. There is little doubt that ***net negative emissions*** will be required to meet net zero in 2050, given the current emissions trajectory and expected emissions gap shown earlier (Fig. 1).

The same concept of net negative emission values has been applied globally. A recent European forecast indicates that ***17Gt negative emissions*** is required worldwide by 2050 to ***"balance the residual emissions"***, that is, to close the gap.

Implications of renewable growth

The necessarily steep growth of renewables behind all "Pathway to Net Zero" scenarios has serious implications that must be considered by planners when integrating renewable energy supplies into the grid.

Fig. 3. **U.S. historic greenhouse gas emissions (1990-2020)** and projected emissions under goal of *Net-Zero 2050*. Targets for 2025 and 2030 are ~27% and ~51% reduction below 2005 peak level, respectively. Decarbonization of electrical sector will help U.S. reach 2030 and 2050 goals in combination with broad electrification of end uses. (Source: *The Long Term Strategy of the United States: Pathways to Net Zero Greenhouse Gas Emissions by 2050, U.S. Executive Office, November 2021*)



Regulatory policies which set Renewable Portfolio Standards (RPS), also called Renewable Electricity Standards (RES), increase the use of renewable energy sources for power generation.

These policies require (or "encourage") utilities to supply their customers with a stated minimum share of electricity from eligible renewable resources and, importantly, they ***give renewables a right to "first dispatch"***. If a renewable asset can generate power, the utility must manage its integration into their supply curve, ahead of conventional assets.

The utility is then forced to include rapid, start/stop and load/unload capabilities into their conventional assets, most commonly gas-fired units, to manage the intermittency of these renewable sources.

As a consequence, the conventional units suffer from both reduced load factors, and off-design and less efficient operation, reducing the overall benefit of the renewable addition.

These new operating requirements on fossil-fueled assets greatly complicate the adoption of any CCS concepts to reduce CO_2 emissions at their source.

High percentage of renewables also greatly complicates the building and integration of advanced 60%-plus efficiency gas-fired combined cycle plants.

- The reduced load factors push gas turbine deployments toward unabated simple-cycle peaking and grid backup units, with efficiencies on the order of 35%-40%.
- The capital cost adder for CCS is not supported by the reduced load factors so the cost per tonne CO_2 captured becomes too high be offset by a potential penalty/price on CO_2 emissions
- The emerging load profile to accommodate expanding renewables is incompatible with the operating needs of the NGCC and, especially, the CCS system which prefers steady state operation.

Integrating variable outputs from renewables will require CCS systems to load follow, either with similarly rapid-response CCS systems or storage component to balance out the duty.

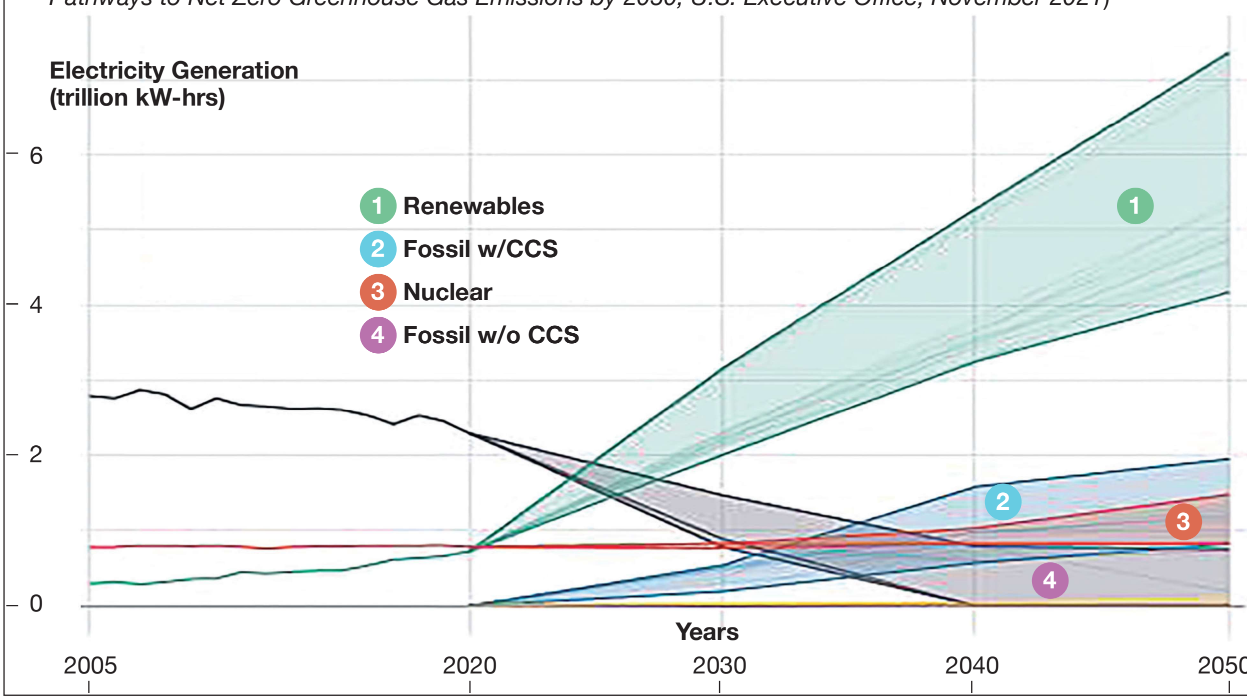
In California, as the penetration of renewables increases, battery storage has become necessary for renewables to be considered a contribution to the Effective Load Carrying Capacity (ELCC) of critical hours, in different regions.

Now, for solar PV to be considered viable for load carrying capacity and get access to power purchase agreements for new capacity, it must be paired with 4-hour storage to cover the marginal day in California.

In Europe, recent news from Germany is an announcement by the Greens Coalition of a plan to accelerate the country's energy transition. The goal is for 80% renewables by 2030, up from about 50% today.

This aggressive plan includes exiting from coal (~25% share today), ideally by 2030, and continued decommissioning of their nuclear fleet (12%).

Fig. 4. U.S. Electricity generation mix 2005-2050 by source, Total U.S. power generation expands through period due to increasing use of clean electricity in transportation, industry and buildings. Renewable generation increases rapidly to keep pace with demand as fossil-fuel share declines. Note introduction of fossil w/CCS in early 2020s with potential for growth to partially replace share of fossil w/o CCS. Share of nuclear is seen growing beyond 2030. Minor contributions of biomass and non-fossil combustion are not shown. *(Source: The Long Term Strategy of the United States: Pathways to Net Zero Greenhouse Gas Emissions by 2050, U.S. Executive Office, November 2021*)



Under this plan, the increased dependence of Germany on natural gas (today only 12% share) goes without saying, and the Greens appear to be silent about it. This also explains Germany's strong position on the need to complete the Nordstream 2 natural gas pipeline from Russia.

Renewables set record. According to IEA's December Renewables 2021 Market Report:

- The world's capacity to generate electricity from renewable sources such as wind, solar and hydro is on track to set a new record in 2021.
- By 2026, global renewable electricity capacity is forecast to rise over 60% from 2020 levels, reaching the equivalent of the current total global power capacity of fossil fuels and nuclear combined.
- Renewables set to account for ~95% of the increase in global power capacity through 2026, with solar PV alone providing more than half of the growth.
- China is expected to remain the global leader in the volume of renewable capacity additions over the next five years.
- India is set to enjoy the fastest rate of growth.
- Deployments are expected to speed up in the U.S. and the European Union, with these four markets accounting for 80% of capacity expansions worldwide.

However, even faster global growth – in renewable electricity, and also other areas such as biofuels and renewable heat – would be needed in a pathway to net zero emissions by mid-century.

One final observation

The recent U.S. legislation and subsequent measures around the world seem to track with the May 2021, **IEA Net Zero by 2050 Special Report** which states that:

1) most of the global reductions in CO_2 emissions through 2030 in their pathway come from technologies readily available today (interpreted to mean fuel switching from coal to unabated-gas); and

2) beyond 2030, their CO_2 projections depend on widespread use of emissions reduction technologies not yet on the market, specifically Hydrogen and Direct Air Capture!

This is "magical thinking", planning on technology breakthroughs. Planning on hope (or is it hoping on a plan?) is not a solution! Understand, we are talking about the vital Electric Power Supply Chain here, and we must be very careful!

I am on record as saying the Climate Change will become the world's shared purpose. I want to amend this to **"Climate Change has become our children's shared purpose."** I have no confidence we, the "adults in the room", are up to this task.

Forgive my pessimism, but we're in trouble! ■